NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

PROPOSED LETTER TO THE EDITOR

VARIABLE FIELD IMAGE INTENSIFICATION IN THE ION MICROSCOPE

by Victor G. Weizer

Lewis Research Center
Cleveland, Ohio

Prepared for

Journal of Applied Physics

September 18, 1964

[redacted] 64-44

E-2717

VARIABLE FIELD IMAGE INTENSIFICATION IN THE ION MICROSCOPE

by Victor G. Weizer

Lewis Research Center
National Aeronautics and Space Administration
Cleveland, Ohio

There is a need for image intensification in field-ion microscopy. This is especially so for operation with small tip radii and for operation with imaging gases other than helium. Attempts to amplify the output intensity of the field-ion microscope may be divided into two categories: (1) conversion of the primary ion beam into an electron beam, the power of which is subsequently amplified, and (2) amplification of the primary ion beam power.

In the first category are the efforts of McLane, et al.[1] and Brandon, et al.[2], who have used external image converters, optically coupled to the microscope, and von Ardenne[3] and Brandon, et al.[2], who have attempted image conversion within the microscope envelope. The external amplifiers have the advantage of obtaining intensity gains of the order of 1000, but they are very expensive and there is loss of resolution, especially at low input light levels. The internal converters, giving gains of the order of 5, are bothered by loss of resolution and contrast.

There are two methods of increasing the primary beam power. These are (1) to increase the beam current, and (2) to increase the energy of the beam ions. Waclawski and Müller[4] have increased the pressure of supply gas available to the emitter and thus increased beam current. A maximum increase in intensity of the order of 50 has been obtained. Difficult electrode alignment problems and high rates of screen phosphor degeneration are attendant to this method. Furthermore, current amplification systems are not applicable to tip radii that are so small that their picture voltages are below the threshold for phosphor excitation.

The suggestion of increasing ion energy by postacceleration was first made by Müller[5] and carried out by Brandon[2]. Typical gains of the order of 5 in

[redacted]

exposure time were reported, but because the ion beam passed through an accelerating grid, at least 30 percent of the ion beam was lost to the grid, and the resolution was decreased.

The purpose of this paper is to describe another method of intensifying the image by increasing the energy of the beam ions. It is based upon the relation between the applied voltage, the field at the tip, and the geometrical arrangement of the electrodes. The normal geometry in an ion microscope is as in Fig. 1(a) and may be described approximately as a point emitter and a planar accelerating electrode. If, however, another electrode at the same potential as the tip is introduced into the system (M in Fig. 1(b)), the voltage-field relation may be changed drastically. Let us consider the limits as M is moved. If M is placed a large distance down the shank of the tip wire, the field at the cap of the tip is as it would be if M were absent. If M is moved up the shank to a position as in Fig. 1(c), the field at the cap of the tip is decreased to approximately that at M. Thus the field at the cap of the tip can be varied through a large range while the voltage on the cap remains constant. An ion produced at the emitter surface will be accelerated to the energy qV, where q is the charge on the ion and V is the applied voltage, regardless of the field at the tip. Therefore, even the smallest tip can be imaged at a brightness determined by the selection of an accelerating voltage that is limited only by the electrical breakdown characteristics between A and M, which is of the order of 100 kV[6]. There should be no limit to the use of extremely small tips other than the ability to make them.

Fig. 2 is a photograph of a 220 Å tungsten tip taken by using the variable field method with an applied voltage of 20 kV. Normally, in a conventional microscope, this tip would have been imaged at about 4.5 kV. The exposure time has been reduced by a factor of 90, while the resolution has remained unchanged.

In certain unusual cases, this phenomenon can be seen to occur without the use of an auxilliary electrode. Two of such cases are pictures in Fig. 3. Fig. 3(a) pictures the stub of a tip after rupture where one or more peaks of small radius are imaged on the screen when the voltage is raised to some high value. Here the remainder of the stub acts as the electrode M and modifies the field so that intensity amplification takes place. Fig. 4 is a photograph of such an occurrence taken at 30 kV.

Fig. 3(b) is the profile of a tip that has changed shape because of the phenomenon of "water etch" described by Müller[5]. Here again the portion of the tip behind the protrusion would modify the voltage-field characteristics so that image intensification could occur. Müller has reported imaging water etched tips with radii as small as 50 Å[5].

The use of gases other than helium in the microscope has the disadvantage that the phosphor response of these gas ions is small at normal operating voltages. It should be possible with the variable field method of image intensification to operate the microscope with gases of lower ionization potentials than have yet been used. This would permit viewing weak tip materials that as yet are not possible to image.

As was brought out by Brandon[2], the greater penetration of high-energy ions into the phosphor spreads the phosphor damage over a larger volume, and thus the rates of phosphor efficiency in ion energy amplification systems are not as great as in similar operation with current amplification systems. Using high voltages does, however, shorten the life of the phosphor screen, and at this laboratory a binderless settling technique such as described by Young[7] has been used to change screen phosphor quickly and easily.

The one difficulty encountered with the variable field amplification system was due to the fact that the field along the shank of the tip wire was reduced to such a degree by the electrode configuration that the "water etch" effect described by Müller[5] was very active unless very clean vacuums or low temperatures were used.

REFERENCES

1. S. B. McLane, E. W. Müller, and O. Nishikawa: Bull. Am. Phys. Soc. Ser II 8 431 (1963).
2. D. G. Brandon, S. Ranganathan, and D. S. Whitmell: Brit. J. App. Phys. 15 55 (1964).
3. M. von Ardenne: Tabellen der Elektronenphysik, Ionenphysik und Uebermikroskopie, Berlin, Wissenschaften: Deutsche-Verlag 1 581 (1956).
4. B. J. Waclawski, E. W. Müller: J. App. Phys. 32 1472 (1961).
5. E. W. Müller: Advances in Electronics and Electron Phys. 13 83 (1960).
6. H. W. Anderson, Elect. Eng. 54 1315 (1935).
7. J. R. Young: J. App. Phys. 26 1302 (1955).

E-2717

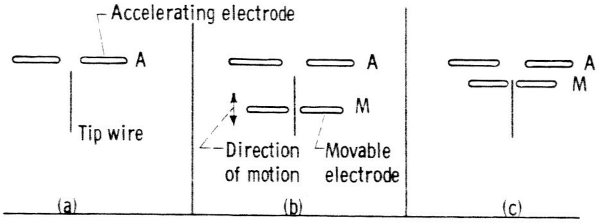

Fig. 1. - Electrode configurations. (a) Normal configuration. (b) Configuration with movable electrode introduced. (c) Position of movable electrode for minimum field at tip surface.

Fig. 2. - An approximately 220° A tungsten tip at 20kV and 78° K.

E-2717

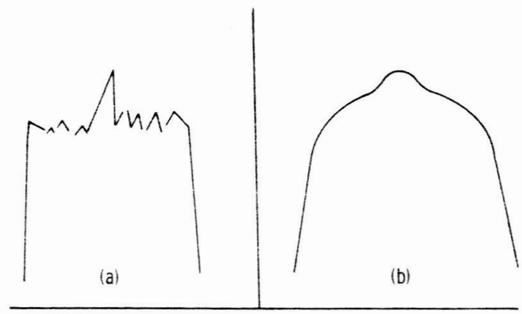

Fig. 3. - Self-amplifying tip shapes. (a) Small peak remaining after tip rupture. (b) Water etch end form.

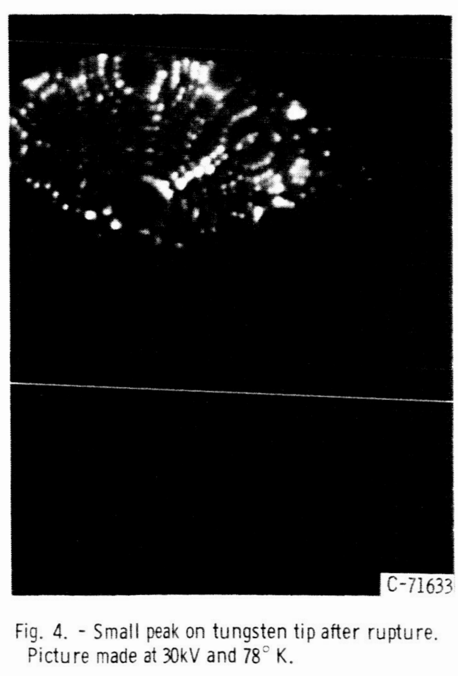

Fig. 4. - Small peak on tungsten tip after rupture. Picture made at 30kV and 78° K.